***Note**: The following article was presented in lecture format on the occasion of the 100th anniversary of the founding of the Verband Deutscher Geigenbauer (VDG = Association of German violinmakers) at their annual meeting on May 22, 2004 in Wiesbaden, Germany.*

ZEITGEIST AND VIOLINMAKING

MILESTONES OF ART AND SCIENCE – A BRIEF JOURNEY THROUGH TIME

Nowadays, the prevailing opinion about the great Italian masters of violinmaking from the 18th century is that those famous makers created their epochal works based on "gut" feeling. Since modern science did not yet exist, the development of the violin must have been a purely "intuitive" process. I intend to question this viewpoint – which might possibly be held by the majority of persons here – by sketching out a brief outline of science and research in the field of violinmaking.

Gifted Empiricists

Anyone who simultaneously studies the history of art and science is sure to come to the following conclusion about the development of the violin: There is simply no way that the famous masters of violinmaking locked themselves away with their art. They did not hide away in secret workshops, far removed from any worldly considerations. Quite the contrary: They were extremely receptive to methods, ideas and discoveries made in science and the arts of their age, including architecture, the natural sciences, composition and painting. The violin as resonance corpus – being, as we know today, a highly optimized acoustic system – must necessarily have arisen in a milieu of great empiricism. Gifted empiricists were at work who would have never felt any inner inconsistency with regard to the conflicting worlds of art and science.

The great masters of the art of violinmaking were not just artists, however. Without any doubt whatsoever, they were also empirical scientists. The reason is that they were plainly capable of learning through a process of "trial and error". The violin owes its development to this "empirical art". The instrument did not develop in a milieu of spontaneous capriciousness (or whimsy) but rather through a sort of integral intuition. It is true that intuition has been often equated with whimsy. However, whimsical efforts are characterized by an inability to distinguish between correct and incorrect, while intuitive work is always guided by an inner body of experience. Proper conclusions are reached through untiring attempts and necessary failures.

The Age of Science

The violin was born in an age of "scientific revolution" which must have made a deep imprint on the world of experience of the first violinmakers:

- During the childhood years of Andrea Amatis, an "intellectual earthquake" occurred in human awareness when Copernicus proposed that the earth rotates with other planets about the sun (1512). Old beliefs came crashing down. The age of science had begun.
- Nicolo Amati had not yet been born when Johannes Kepler (1571 – 1630) founded theoretical astronomy.

“Harmonices mundi” (English: “World harmony”) contained Kepler’s third law of planetary motion.
- His contemporary, Italian Galileo Galilei (1564 – 1642), founded modern experimental physics. In the year 1589 – seven years prior to the birth of Nicolo Amati – Galileo was awarded a teaching position for mathematics in Pisa. His “golden rule of mechanics” became famous with its principle of conservation of mechanical energy (1594).
- Stradivari had not yet been born when in 1640 a French priest named Marin Mersenne calculated the speed of sound in air. (He accomplished this by comparing when he saw the flash from a gun and when he heard the gunfire. Bacon had performed a similar experiment in the year 1600).

We can name many more great scientists from that era who reflect the pioneering spirit of the age of science (which happens to be the same age in which the development of the violin has its roots). Further examples include:

- Santorio (1561 – 1636) invented the modern humidity meter. This gives us good reason to assume that an understanding of quantities such as wood humidity was widespread among violinmakers, allowing them to ask questions about favorable and unfavorable material properties.
- If we recall that in the year 1672 (Stradivari was in his mid-20s), Isaac Newton was in the process of separating sunlight into spectral colors with a prism, it is not hard to imagine that terms such as “tonal color” would be in everyday use among violinmakers of that time. One thing was clear: Colors arise for reasons that can be explained by the natural sciences …
- With the paradigm shift that resulted from the new world view of the early 16th century, the development of science underwent a veritable explosion. For instance, the Royal Society was founded in England in 1662 and four years later, the Académie Royale des Sciences in Paris.

Influenced by music and mathematics

In my opinion, the violin received its most significant impulses through confrontations with the science and art of that era. Certain major interactions between developmental forces acting on the violin on the one hand and milestones of music history on the other hand are clear:

- Claudio Monteverdi was the first composer to require the use of the fourth position (e3 Vespro della Beata Vergine, 1610). This advanced the technical level of virtuosity expected of violinists compared to other composers of this era. Monteverdi was born in Cremona. In view of Monteverdi’s close proximity to the Amati dynasty, we can reliably assume that his technical demands directly promoted further technical development of their instruments.
- Arcangelo Corelli’s 12 violin sonatas (“Sonata a violine e violine o cimbalo”, 1700) became a standard work in the violin literature which remained an integral part of every violinist’s studies into the 19th century. The year 1680 might have been even more important with the birth of the “concerto grosso” by Corelli. This had the effect of emphasizing the violin within the orchestra (only during certain phrases at first) and move it towards becoming a solo instrument. We expect this must have represented a musical revolution for the young Stradivari and his contemporaries. He now began to move away from the arching and design preferred by his master Nicolo Amati and develop his own “long model”. This was his way of rising up to the challenges of the new music he heard.
- No doubt Stradivari's creative power was given an even greater impulse in 1698. This was the year that Torelli wrote the first virtuoso violin concerto. Stradivari responded to this revolutionary development with a new model. This was the start of what later generations would call his "golden period".
- Moreover, the development of the modern bow by Francois Xavier Tourte (Paris, 1747 - 1835) would have never been “tolerated” had it not been for the new violin schools of the likes of Leopold Mozart and Josef

Haydn. Just as the new concert situation necessitated new instruments, the new playing techniques required new bows.

The golden age of Italian violinmaking would have been inconceivable without a direct response to such musical developments. What arose was a sort of living interaction between the virtuosity demanded by the composers and the state of constant, creative openness and developmental readiness practiced by the violinmakers of that era.

Art and geometry

We can also see definite traces left by the influences of mathematics and architecture in violinmaking:
In Renaissance architecture, it is common to see an underlying shape known as a "cycloid" used in arches, curves and domes. A cycloid is a line generated by a point on a circle rolling along a straight line. If the point is situated inside the circle, then what arises is known as an "inflected cycloid". Most recently, Quentin Playfair has written about the impressive correspondence between classic Italian violin arching profiles and cycloid curves [see "Cremona's Forgotten Curve", The Strad, November 1999].

My own arching measurements on typical Cremonese and Venetian instruments have also shown that based on the choice of the insertion point of the circle and the wheel diameter, each of the five cross-templates can be sketched and the basic nature of the arching can be determined. Typically, in the case of instruments made by Amati, the cycloid minimum will lie within the violin contour. For Stradivari, it is generally in the region of the outer contour line. Finally, for Guarneri "del Gesu" it is outside of the contour line.

Due to a "harmonic" aesthetic sense, designs and drawings of curves and arches based on cycloids enjoyed great popularity in Renaissance architecture. Although the form of the cycloid was known in ancient Greece, the necessary mathematics to precisely characterize it did not yet exist. In the Renaissance, the relationship between art and geometry was a given.

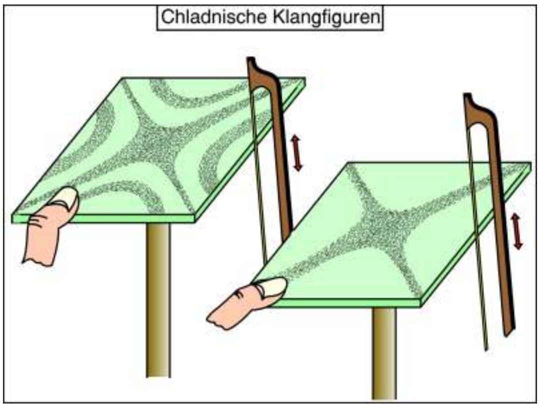
- For example, Albrecht Dürer (1471-1528) examines the theoretical underpinning of his art in his treatises on geometry, fortifications and human proportions. In his writings, he offers detailed explanations of basic geometrical principles including how to construct different curves and how artists and craftsmen can best exploit this information. In the field of descriptive geometry, Dürer pushed the limits of contemporary mathematics and inspired the works of Galileo and Kepler to a significant extent.
- The design of the Ponte di Mezzo bridge in Florence is based on cycloid computations by Galileo (1564-1642). Besides Galileo, many famous mathematicians of the 17th century such as Pascal (1623-62), Leibniz (1646-1716) and Newton (1643-1727) intensively examined the mathematics and physical applications of cycloids.

From Albrecht Dürer through Isaac Newton (meaning from the time of Andrea Amati through Antonio Stradivari), the cycloid would have been part of the basic knowledge of any trained person. I cannot imagine that the violinmakers of that era somehow did their work in isolation or ignorance of such major scientific insights.

The violin's arching is one of the main elements that influences the sound. In view of this cycloid example, it is clear to me that violins were made with much more than just "gut" feeling during the development and golden age of the instrument. The makers were masters of the fundamentals of geometry and construction techniques and made consistent use of them. They were influenced by discoveries in mathematics and physics, applications of architecture and developments in art and music.

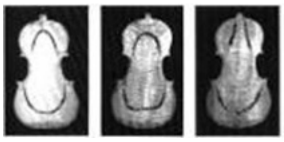
The succeeding age - The 19th century

It seems to me that violinmaking and science tended to move away from one another as they developed in the succeeding period. As a consequence of the “industrial revolution”, there was an increasing trend towards finding more efficient production techniques for use in copying proven models (as opposed to a creative confrontation between the different impulses from art and science). In the field of acoustics, however, the 19th century was an age of fundamental discoveries. The “fathers of modern acoustics” included names such as Chladni, Fourier and Helmholtz.



Source: http://www.av-medien.net/index.html?c~4

- In the year 1787, Ernst Florens Friedrich Chladni (1756-1827) published the results of his research in a treatise entitled "Entdeckungen über die Theorie des Klanges" (English: “Discoveries concerning the theory of sound”). He noted that by drawing a violin bow across freely suspended plates, the patterns of their eigenmodes of vibration could be observed. As seen in the sketch, the plates were first covered with sand. As a result of the ensuing vibrations, the sand would then drift from the antinodes to the node lines (assuming a suitable choice for the plate support and bowing point):



Source: www.uni-erfurt.de/ kommunikationswissenschaft

During the 20th century, this methodology has been frequently used in violinmaking (in conjunction with an electronic function generator) in what is known as “free-plate tuning”. The next figure shows the mode shapes that can be seen on the bottom of a violin using this technique:

- J.B. Fourier showed in 1822 as part of his investigation into the nature of heat (“Theorie analytique de la chaleur”) that a process having any arbitrary form which repeats over a period T (e.g. the vibration of a bowed violin string) can be constructed entirely from individual harmonic frequency components. The fundamental and harmonic vibrations are now known as “Fourier components”.
- The Fourier transformation harks back to this principle, and is an algorithm for transforming signals from the time domain into the frequency domain. Using a Fourier transformation, it becomes possible to see all of the frequency components that make up a process that is a function of time. In the 1970s, computers made it possible for the first time to use Fourier’s 150-year-old algorithm in a wide range of applications. Nowadays, the fast Fourier transform (FFT) is probably the most commonly used technique in the engineering sciences. Computer-based modal analysis used to display the vibration behavior of structures is also based on the fundamental principles of Fourier’s work from 1822.
- In 1865, Hermann Ludwig Ferdinand von Helmholtz (1821-1894) published his now famous work “Lehre von der Tonempfindung” (English: "Treatise on sound perception”). This marked a new milestone in the awareness of the acoustics of our hearing. By inserting an opening in different sizes of glass balls into the external auditory canal of the ear (see figure above), he invented a basic type of spectral analysis of sound. The air resonance mechanism which he demonstrated in his experiments is known as “Helmholtz resonance” in his honor. Through its f holes, the violin also exhibits a Helmholtz resonance which is responsible for radiation of the low-frequency fundamental range.The sawtooth vibration behavior of a bowed string is also named after Helmholtz.
- Lord Rayleigh's “Theory of Sound” (1877) became a standard work in acoustical science. It contains diverse information on computations relating to vibrating structures and covers topics such as radiation, diffraction and dispersion of sound.

Developments in the 20th century

In the year 1907, Lee de Forest invented the vacuum tube. This opened up new horizons in the field of acoustics by making it possible to record, save, play back and analyze sounds using electronic equipment.
A new research area known as “psychoacoustics" was born which attempts to determine the relationship between the physical properties of a sound signal and the resulting perceptions within our hearing, i.e. the relationship between physical stimuli and psychic perception variables.
In the area of instrumental acoustics, a number of fundamental works were authored which provide insight into the acoustic functioning of instruments. This includes the standard work “Die Physik der Geige” [English: “Violin physics”, Stuttgart 1981] by L. Cremer, or comprehensive textbooks such as “The Physics of Musical Instruments” by N. H. Fletcher and T. D. Rossing [New York 1991] and “Fundamentals of Musical Acoustics” by Arthur H. Benade [New York 1976].

I should also mention the Catgut Acoustical Society which thrived over many decades due in no small part to the committed efforts of Carleen M. Hutchins. In the 2nd half of the 20th century, the society helped to bring together a small, international community of ambitious acoustics researchers, instrument makers and violin lovers who meet regularly to exchange the results of their research through the International Symposium on Musical Acoustics (ISMA).
Of course, there is not enough time now to cover all of the research that has occurred in the field of violin acoustics in the 20th century. But I will also mention the biannual journal of the Catgut Acoustical Society as well as "Research Papers in Violin Acoustics 1975-1993" [Acoustical Society of America, 1997]. They contain over 120 articles with research results on topics such as sound radiation, the bowed string, bridges, soundposts, plate vibrations, air resonance, wood, varnish and psychoacoustics.

The following authors have produced highly practical results that I find worthy of note:

- Eric Jansson ("Department of Speech, Music and Hearing" KTH Stockholm)
- Helmut A. Müller (Müller-BBM) who was the first person to demonstrate the acoustic functioning of the violin with the aid of modal analysis in 1983
- Jim Woodhouse (Cambridge University, UK) who has performed EDAX analyses on primers and wood analyses on old Italian violins using scanning electron microscopy

In view of the current "climate" in violinmaking, I find it noteworthy that the divide between university research and practical instrument making seems to be growing smaller. Violinmakers are becoming increasingly aware of analysis techniques from the field of acoustics and more receptive to research results in general. Current evidence of this progression can be seen in the fusion of the Catgut Acoustical Society with the Violin Society of America. The annual Oberlin Workshops in the United States give equal voice to issues relating to acoustics research, tonal adjustment and workshop methods and provide further evidence that violinmaking is beginning to get past its former closed, "in the privacy of my own workshop" attitude.

Visions and Developments

I suspect that violinmaking studios of the future will integrate acoustical laboratory techniques into their daily work environment to a much greater extent. New and innovative measuring devices will come into use as "diagnostic tools" for examining material properties and sound characteristics.
Newly developed bowed stringed instruments of the future will be better adapted than previous instruments to the acoustic demands of today's large concert halls. When combined with the natural appeal of wood, the discovery of the acoustic potential of carbon fiber should allow the creation of instruments with wider dynamic bandwidth and greater modulability than ever before. (Wood reached the limits of its potential in the first half of the 18th century. With wood alone, there is simply no way to outdo the material characteristics of top instruments by Stradivari). However, I have no doubt that if Stradivari were alive today with the same force of innovation, he would have already discovered the fascinating acoustic properties of carbon fiber composite materials and would have ushered us into a new golden age of violinmaking.

Conclusion

I hope to have clearly described the milieu in which the violin arose and in which it can continue to evolve. The more one learns about the acoustic system that is the violin, the more one is astonished by the intelligence embodied in this system and the more one must wonder how such intelligence came about. I am convinced that in any case the forces I have described above played a major role in the process. They might even encourage us on the occasion of our 100-year anniversary to ask constructive questions about the creativity and openness of our organization.

One important characteristic of intelligence is openness, i.e. the capacity to take in new things and integrate them into one's own growth and work. Intelligent systems that are capable of development communicate and interact with their environment in order to make creative use of outside stimuli in their own processes.

As we celebrate the 100-year anniversary of the Verband Deutscher Geigenbauer (VDG), we might take advantage of this opportunity to ask ourselves how future generations will look back on us in 100 years: Will they see us as creative or narrow-minded; as open or insular; or as innovative or "asleep at the wheel"?

How do we interact with developments to the right and left of our field of vision? Where is our creative "battlefield" between art and science? Should we perhaps recruit new members into the VDG who are novices in the field of violinmaking but forerunners in their own fields? I am thinking of architects, physicists, composers, historians, sculptors, musicians, brain researchers and so on.

A compelling association of violinmakers will have to be one which sends out strong impulses, encourages interactions with representatives of and developments in music, art and science, and keeps alive the tension that exists between tradition and innovation and between continuity and renewal.

As part of a lecture entitled "Musical Acoustics in the Twentieth Century" that he gave on the occasion of the 75th anniversary of the Acoustical Society of America, Gabriel Weinreich, who is one of the great acousticians of our time and also a professor of physics at the University of Michigan, concluded as follows (which I am pleased to quote here without qualifications): "Finally, I must say that there is a certain appeal that is inherent in researching musical instruments. The reason is that over the centuries (or maybe over the millennia in some cases), a very impressive sort of genius has been attained in the construction of these instruments through a process of "trial and error". There is something fulfilling about attaining some small bit of logical insight with regard to the unique and mysterious nature of musical instruments and then beholding with great reverence the works that mankind has been capable of developing over the ages – through intuition, patience and the grace of God."